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Revisiting accretionary history and magma sources in the Southern Andes: Time variation of "typical Andean granites"

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Southern Andes: accretionary history of the basement blocks

The composition and distribution of Andean magmas are strongly influenced by the age and extent of the different basement blocks beneath the modern Andes. In particular, radical revision of southwestern Gonwana assembly models depicted in recent studies has to be taken into account when considering the variation with time of the early pre-Andean and Andean subduction-related granitic magmas (Fig. 1): (i) Palaeomagnetic studies indicate that one of the most important assembly episodes occurred during the Pampean-Araguaia collisional orogeny (540-520 Ma), between an Amazonia craton group and the West Africa, Congo-São Francisco, Paraná and Río de la Plata cratons (Trindade *et al.*, 2006 and references therein); (ii) The Amazonia craton group included the Arequipa-Antofalla and Western Sierras Pampeanas basement blocks (Rapela *et al.*, 2007), for which a common metamorphic and magmatic history has been established (Casquet *et al.*, 2006; 2008); (iii) Further evidence shows that the large Neoproterozoic turbiditic sequence of the Eastern Sierras Pampeanas (Pampean belt), now bounded to the east by the Palaeoproterozoic Rio de la Plata craton, is a transcurrent terrane resulting from right-lateral movements along the SW Gondwana margin (Rapela *et al.*, 2007). This dextral displacement was associated with the oblique collision of the Western Sierras Pampeanas during the Pampean–Araguaia orogeny, following closure of the intervening Clymene ocean (Fig. 2); (iv) South

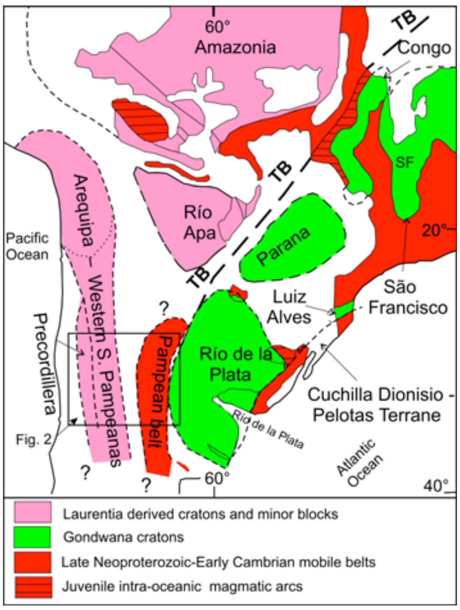

Figure 1. Group of cratons and minor blocks amalgamated in the Pampean-Araguaia orogeny (540-515 Ma) (modified from Trindade *et al*., 2006 and Rapela *et al*., 2007).
TB = Transbrasiliano shear zone.

of 36ºS, the last recognised accretion to the already assembled Gondwana took place during mid-Carboniferous time, when Early Carboniferous I-type granites representing a subduction-related magmatic arc was followed by a collision between continental areas typified by the Deseado and North Patagonian massifs (Pankhurst *et al.*, 2006).

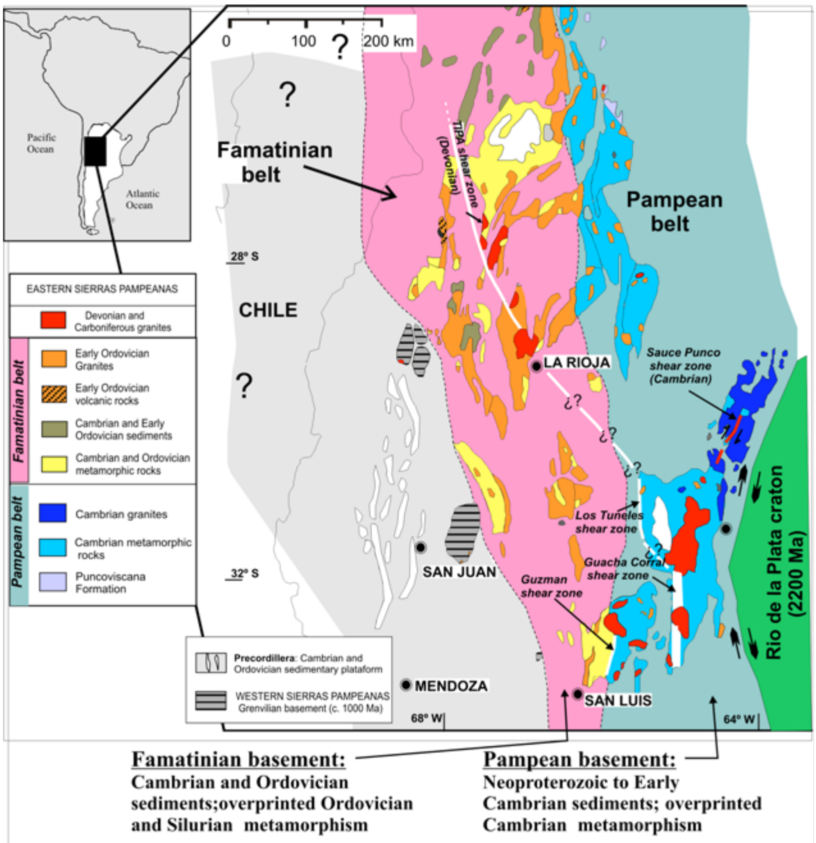

Figure 2. Precambrian and Early Palaeozoic terrains in the Southern Andes, disclosed by back-thrusting above Miocene "flat-slab" subduction (28° - 33ºS).

Subduction associated with pre-Andean episodes was related to Wilson cycles of ocean opening and closing, where the final event is either a continent-continent collision or large-scale back-arc closure. At 30º-34ºS, three main episodes of pre-Andean plate convergence are well established: (1) Pampean: 540-528 Ma subduction, followed by oblique continent-continent collision at 528-515 Ma. The supercontinent grew westwards by lateral accretion of the Western Sierras Pampeanas Grenvillian block (Rapela *et al.*, 2007), including the Precordillera (Fig.2). (2) Famatinian: 484-463 Ma convergent episode associated with the opening and closing of a large back-arc basin in Early to Mid Ordovician times (Pankhurst *et al.*, 2000; Dahlquist *et al.*, 2008) (Fig.2). (3) Gondwanan: 320-190 Ma. After the intrusion of Devonian and Early Carboniferous (*c.* 380 and 340 Ma) intra-plate A-type granites in the Sierras Pampeanas, a new subduction regime started along the palaeo-Pacific margin in Late Carboniferous times (*c.* 320 Ma), which included younger pulses (Parada *et al.*, 1999). At 33ºS the Late Palaeozoic batholiths occur both in the coast range of Chile and in the Frontal Cordillera, suggesting that no major continental accretion took place after the collision of the Western Sierras Pampeanas and associated Grenvillian blocks.

Isotopic and chemical variations of the subduction-related granites

The isotopic and chemical characteristics of the granites emplaced in the different pre-Andean episodes described above are compared with the typical Andean I-type granites emplaced near the continental margin after the break-up of Gondwana. The latter are mostly Cretaceous in age at 30º-34ºS, but a complete record from 185 Ma to Tertiary is exposed in the Patagonian batholith and subcordilleran belts (Rapela *et al*., 2005, Hervé *et al*., 2007). The Pampean and Famatinian rocks have chemical and isotopic characteristics that contrast with the younger Andean bodies. The older pre-Andean rocks show a wide silica range and, although metaluminous I-type varieties from gabbro to granodiorites are abundant, cordierite-bearing S-type granites are also conspicuous. S-type granites are rare in the Carboniferous and Andean granites, indicating that melting of sedimentary material was not common in these episodes. The εNd_t values decreases with time, suggesting derivation from progressively more primitive and depleted sources. Only the younger Gondwanan and the majority of the Andean granites plot in the "mantle array" of the $(^{87}Sr/^{86}Sr)_0$ – εNd_t isotopic diagram, in contrast to the Palaeozoic granites, most of which lie outside the mantle field, with $\varepsilon Nd_t < -2$ (Fig. 3). This is a remarkably consistent feature of the Pampean and Famatinian events, as they include abundant amphibole-bearing and noritic gabbros with less than 50% SiO_2 that share the same crustal signature as the intermediate rocks. As there is no evidence for massive *in situ* contamination during emplacement in the upper crust, this signature must reflect the composition of the middle or lower crust (Pankhurst *et al.* 1998). Depleted mantle model ages (T_{DM}) for most of the Cambrian and Ordovician rocks, both I- and S-types, are in the interval 1400–1700 Ma indicating involvement of Palaeo- to Mesoproterozoic sources. Altogether the chemical and isotopic evidence suggests that the Pampean and Famatinian episodes did not involve significant recycling of young underplated material. Rather, it indicates melting of an old crustal section, including the underlying subcontinental mantle, to produce the basic rocks with enriched isotopic signatures. Although isotopically less evolved than the Cambrian–Ordovician granites, the Carboniferous coastal batholiths of Chile also plot off the "mantle array", but with younger (mostly Neoproterozoic) model ages. Recycling of the immature 1000–1200 Ma juvenile Grenvillian lithosphere in which they are emplaced seems to fit the source isotopic constraints. Only the Andean and younger Gondwanan granites show depleted signatures (Parada *et al.* 1999): this is not only a characteristic of central Chile but also in the Patagonian Andes (Pankhurst *et al.* 1999, Rapela *et al.* 2005, Hervé *et al.*, 2007).

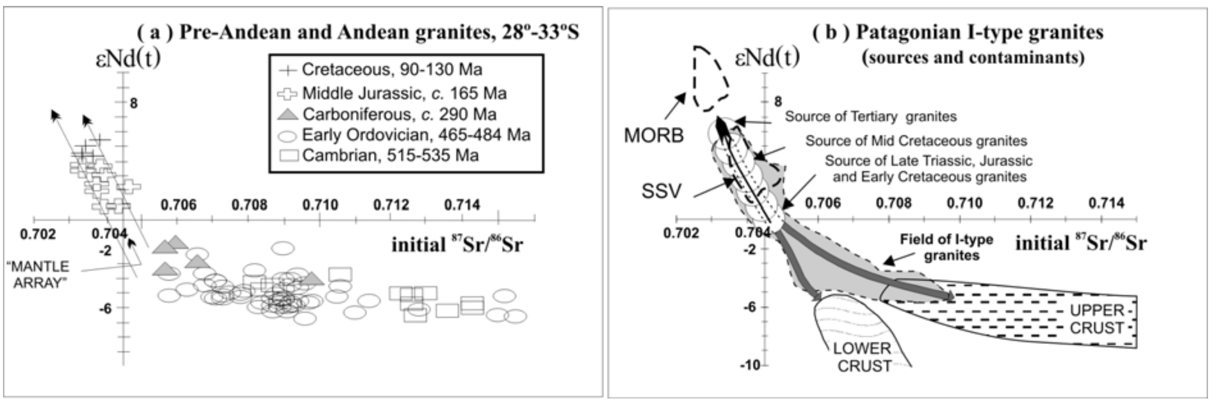

Figure 3. Variation of εNd_t versus initial $^{87}Sr/^{86}Sr$ for the granitic rocks emplaced during the main convergence episodes in the Andean sector at 28º- 33ºS (a) and Patagonia (b). Data sources are Pankhurst *et al*., 1999; 2000, Parada *et al*., 1999, Rapela *et al*., 2005, Hervé *et al*., 2007 and references therein.

Remarkably, the Andean granites also show a change in isotopic composition with time. For example the Sm–Nd relationships of granitoids from the Patagonian batholith at 44º–46ºS indicate source compositions that change from slightly LIL-enriched for the Jurassic and Early Cretaceous rocks, to significantly depleted for the Late Cretaceous to Early Miocene plutons (εNdt values between +4 and +6), the latter in turn very similar to those of the Tertiary to Recent mafic strato-volcanoes of the Southern Volcanic Zones (Pankhurst *et al.* 1999) (Fig. 3). This cannot be explained by upper or lower crustal contamination and it has been suggested that melting occurs in progressively more LIL-depleted mantle sources underlying the Patagonian batholith (Rapela *et al.*, 2005). The obvious conclusion is that under the label of "typical I-type Andean granite" there is a wide range of isotopic compositions that shows a general variation towards more depleted mantle sources with time. Isotopic equivalents of modern Andean granites are uncommon or absent in the extensive Early Paleozoic metaluminous suites.

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